Enhancing Wear Resistance of En45 Spring Steel Using Cryogenic Treatment

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Abstract

Cryogenic Treatment is a supplementary process for conventional heat treatment process in steel. It is an inexpensive one time permanent treatment affecting the entire section of the component unlike coatings. This experimental study investigates the effect of Cryogenic Treatment on the abrasive wear behavior of En45 steel. As the temperature is decreased more retained austenite is transformed to martensite and leads to smaller and more uniform martensite laths distributed in the micro structure. Micro structural analysis was carried out by using optical emission microscope. Pin- On -Disc wear test was also applied and results showed that the wear resistance of the En45 spring steel was improved remarkably after cryogenic treatment.

Keywords

Carbide Precipitation; Cryogenic Treatment; Micro Structural Studies; Subzero Treatment; Wear Resistance

Introduction

En 45 springs steel is used for manufacturing the main components of cultivator. Cultivator is the most common agricultural equipment used for primary tillage in an Indian state Punjab. In Punjab total cultivator used for tillage operation are 2, 85,000 [Bensely et al, 2007]. Reversible shovel are usually fitted on cultivator as soil working tool for many purposes such as loosen the soil, destroy weeds and to mix soil particles. En 45 spring steel material is used in the manufacturing of reversible shovel. The poor quality of the shovel material affects the efficiency of work and leads to the loss of time especially in urgency. Abrasive wear of the soil-engaging components such as shovel of cultivator is a cause of concern as causes damage to material and increases the cost and time lost in replacing worn parts of agriculture machinery. The abrasive wear depends on not only the intrinsic characteristics of the material, but also the service conditions [Bressan et al, 2008]. There are several techniques developed over the year to increase the abrasive wear resistance of soil tools in order to improve the efficiency and agricultural equipments for the help of electro deposition, vapor deposition diffusion coating surface hardening thermal spraying, hard facing, cladding and ion implantation [Chahar et al, 2009; Das et al, 2010].For the past few decades, interest has been shown on the effect of the application of low temperature heat treatments to various types of steel. Cryogenic treatment also known as cold or subzero treatment is widely used for the better performance of the components [Das et al, 2010; Das et al, 2009]. In general unlike surface treatments, the cryogenic treatments influence the core properties of the materials. In order to avoid confusion, a distinction will be drawn between "shallow cryogenic treatment (SCT)", at temperatures down to around -72 ℃ , and deep cryogenic treatment(DCT)" near liquid nitrogen (-196 ℃) temperatures. Deep cryogenic treatment improves certain properties beyond the improvement obtained by normal cold treatment [Yu & Bhole, 1990; Huang et al, 2003; Joseph et al, 2008; Wang et al, 2009; Mahdi et al, 2011; Mohan et al, 2001]. The main reason for using cryogenic CT, is firstly the elimination of retained austenite as well as the initiation of nucleation sites for subsequent precipitation of large number of very fine carbide particles [Molinary et al, 2001]. Cryogenics is neither a substitute for heat treatment nor a coating but an affecting factor of the entire volume of the material. Besides it increases the resistivity of the material especially in wear conditions [PRIMERO LIMITED, 2005; Speich]. The aim of the present work is to investigate the effects of cryogenic treatment on En 45 spring steel, especially on wear resistance as well as hardness.

Experimental Procedure

The experimental procedure adopted in the present

work is shown in Fig. 1. As per the flow chart, the tests were carried out separately for three different treatments. The conventional heat treated (CHT) steel samples used in this investigation were held at 950℃ for one hour and then tempered.

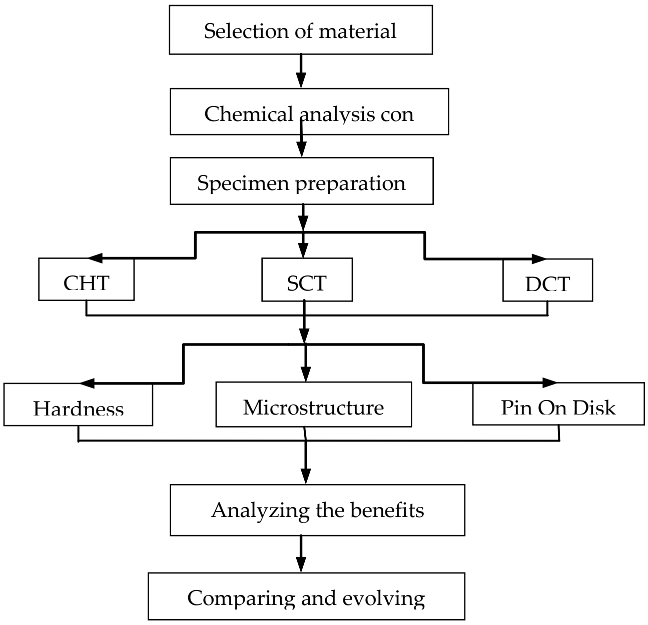

FIG. 1 FLOW CHART FOR THE EXPERIMENTAL PROCEDURE.

Chemical Analysis

The chemical analysis of En 45 spring steel for the confirmation of the material composition, used in this study is presented in Table 1.

TABLE 1 CHEMICAL COMPOSITION OF THE EN 45 SPRING STEEL USED IN THE EXPERIMENTS COMPARED WITH ASTM A-671 STANDARD

Element	En 45 steel (wt %)	ASTM -9255 (wt %)
Carbon	0.60	0.51-0.59
Silicon	1.87	1.80-2.20
Manganese	0.87	0.70-0.95
Sulphur	0.005	0.04 (Max)
Phosphorus	0.021	0.035 (Max)

The composition is in the range of E45 Spring steel based on the ASTM A -671 standard. After the material has been confirmed, it is machined according to the requirement and subject to appropriate treatments as required for the tests.

Conventional and Cryogenic Treatment

All the samples used for experimentation as well as wear and hardness tests, were machined to 6mm diameter and 20 mm length. The machine specimens for conventional heat treatment (CHT) were hardened at 975℃ for one hour and followed by oil quenched and then tempered at 250℃ for one hour.

Cryogenic treatment of samples has been performed by placing specimens in a cryogenic treatment chamber for a cycle 3-8-3 at Auto parts tools Ltd, Ludhiana. The temperature of cryogenic chamber is ramp down from atmospheric temperature to -90℃ in 3 hours and then back to the atmospheric temperature in the same period, followed by tempering at 250℃ for 1 hour. The soaking period is 8 hrs. Deep cryogenic treatment was performed by using 8-16-12 cycle. The temperature of cryogenic chamber is ramp down from atmospheric temperature to -184℃ in 8 hours and then then back to the atmospheric temperature in 12 hours. The soaking period is 16 hrs. This painstaking method eliminates the probability of thermal shock and micro cracking. Specimens were held at both shallow cryogenic temperature at -90℃ and deep cryogenic temperature at -196℃.

Hardness Test

The Vickers hardness measurement was done on the samples prepared as per standard procedures [Yilmaz, 2006] using FIE M50Vickers hardness tester. Hardness measurement was made with a 50N load with a dwell time of 20s. The hardness number is determined, based on the formation of indentation by applying force at the same time sliding velocity remain constant. The instrument has a square-based diamond pyramid indenter with an included angle of 136℃ between opposite faces. The hardness values were taken corresponding to the diagonal length of indentation. The sample is taken for each type of treatment and four readings are taken for each sample.

Wear Test

Abrasion tests were carried out to study the effect of cold treatment cycles wear properties of En45 spring steel. Cylindrical samples (6 mm diameter, 25mm length) were prepared for abrasion tests. The experimental wear resistance results for the En 45 spring steel were obtained by means of the wear testing in the pin -on-disc equipment for a selected constant total sliding distance, constant normal load on the pin as well as the constant sliding velocity. [www.steelgrades.com/steel-grades/carbon-steel/astm-9255.html] Table 3 shows the used parameters during the testing operation. The pins were machined by the conventional methods i.e.turning and grinding to obtain the desired pin shape with a rounded tip. Each specimen was weighed on a weighing machine with a least count 0.0001gm before and after the wear test that was conducted for all the samples of various types treatment such as CHT, SCT and DCT.

The experimental results of wear carried out in laboratory are commonly analyzed by the Archads's (Hutchings, 1995) or Rabinowicz's mathematical formulation (Rabinowicz 1965) that assessed the wear rate and wear coefficient. [www.steelgrades.com/steel-grades/carbon-steel/astm-9255.html] The same was considered herewith in present study.

Wear Rate = Wear Volume/ Sliding Distance

Sliding distance = 2ðRNT/60

R=Radius of abrasive wheel

T=Time

Wear resistance=1/wear rate

TABLE 3 PARAMETERS UTILIZED FOR PERFORMING THE WEAR TESTS

Sliding Velocity (m/s)	250
Load (N)	03
Total sliding distance (m)	1500

Results & Discussion

Micro Structural Evaluation

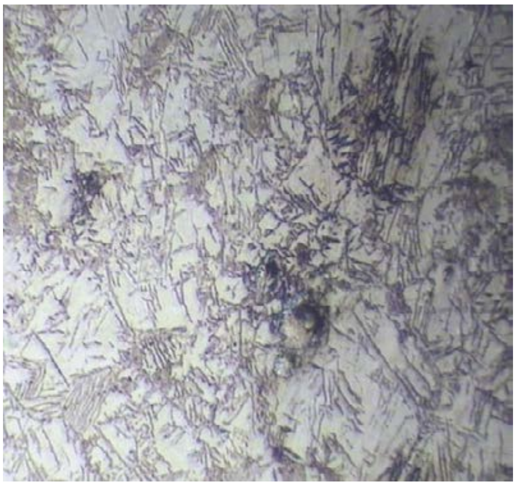

FIG. 2 MICROSTRUCTURE OF EN45 SPRING STEEL (CULTIVATOR SHOVEL) AFTER CHT

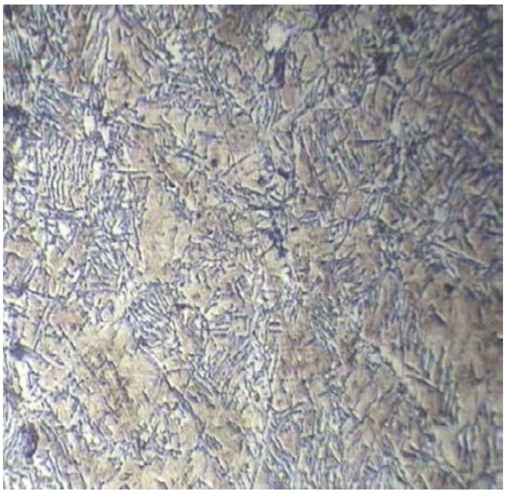

FIG. 3 MICROSTRUCTURE OF EN45 SPRING STEEL (CULTIVATOR SHOVEL) AFTER SCT

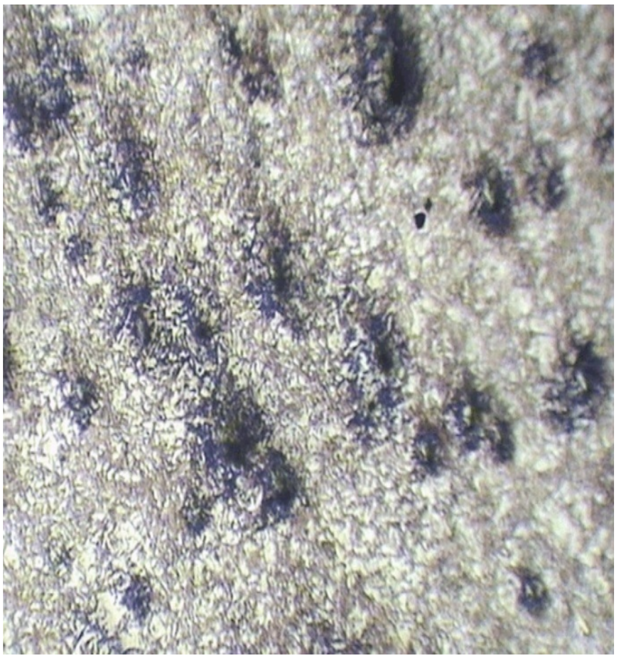

FIG. 4 MICROSTRUCTURE OF EN45 SPRING STEEL (CULTIVATOR SHOVEL) AFTER DCT

The microstructures of all the samples were studied with Leica DM version optical microscope. Bakelite moulds are prepared and the moulds are polished by using emery paper of grit 80, 120, 200, 600, 800, 1000, followed by polishing using diamond paste on rotating linen disc and finished with polishing on velvet cloth using white kerosene as the suspension medium. These samples were etched with 2% nital (nitric acid and ethanol) and dried in air. The etched samples were studied using optical microscope at a magnification of 500×. Microstructure of the CHT, SCT and DCT samples are presented as per Fig.2-Fig 4.

Fig.2 shows the CHT microstructure, the structure consists of untemper marten site and large amount of retained austenite. The grains are larger in size and shape. The white regions represent the presence of retained austenite. The carbide particles are less, which indicates poor precipitation.

Fig.3 shows the SCT microstructure, tempered marten site and some spheroidal carbide particles with some amount of retained austenite whose level is lower as compared to the CHT sample. The grains are smaller in size and shape as compared to the CHT sample.

During deep cryogenic sample as shown in Fig.4, the level of retained austenite is much lower as compared to CHT and SCT sample. The structure consists of tempered marten site with finely dispersed and medium sized spheroidized carbide particles which is precipitated from the martensite matrix.

Hardness

The hardness of the samples after each treatment is presented in Table 4. After the samples were soaked at cryogenic temperatures, the treatment resulted in the increment of the hardness of the samples, which is due to transformation of austenite to martensite and also finer shapes of the laths in the microstructure. Lowering the temperature results in lower change in hardness after most of the austenite is transformed. The average Vickers hardness number and its equivalent Rockwell hardness number are tabulated in Table 4.

TABLE 4 HARDNESS OF SAMPLES OF EN 45 SPRING STEEL

S.No.	Heat Treatment	Hardness
1	Conventional Heat Treatment	54
2	Shallow Cryogenic Treatment	56
3	Deep Cryogenic Treatment	57

It is clear from the table that the CHT has the lowest hardness and the DCT sample has the highest hardness when compared to SCT and CHT samples. This increase in the SCT sample is slight owing to the retained austenite reduction. In the DCT sample, the increase in hardness continues, which is attributed to the retained austenite elimination, more homogenized carbide distribution and higher carbide percentage. The untempered structure has the highest hardness in all the cases but the material is more brittle due to the presence of untempered martensite seen in the microstructure. Hence tempering should be done to reduce the brittleness by scarifying some hardness and tensile strength to relieve internal stresses and increase toughness and ductility.

Wear Test

The most important effect of tempering the deep cryogenically treated samples to improve the wear properties of the samples. The better distribution of marten site laths along with the more uniform and finer distribution of carbides increases the wear properties especially in DCT samples. Wear rate and average wear resistance of all the samples have been calculated and displayed in Fig 5 and Fig 6, respectively, in which the variation of average of wear rate, wear resistance in the samples of the different group with time have been observed. The wear rate of DCT and SCT samples is low as compared to CHT sample due to the reason that the cold treatment process completes the transformation of the steel microstructure from austenite to the stronger and harder martensitic structure. The hardness of steel increases with the growing percentage of martensite in the structure. Thereby wear resistance increases as it correlates positively with hardness. The wear resistance of DCT and SCT samples is higher as compared to the CHT. The wear resistance in addition also depends on the presence of carbides. DCT causes crystallographic and micro structural changes in the material and then tempering results in the precipitation of a finer distribution of carbides in the microstructure with consequent increase in wear resistance.

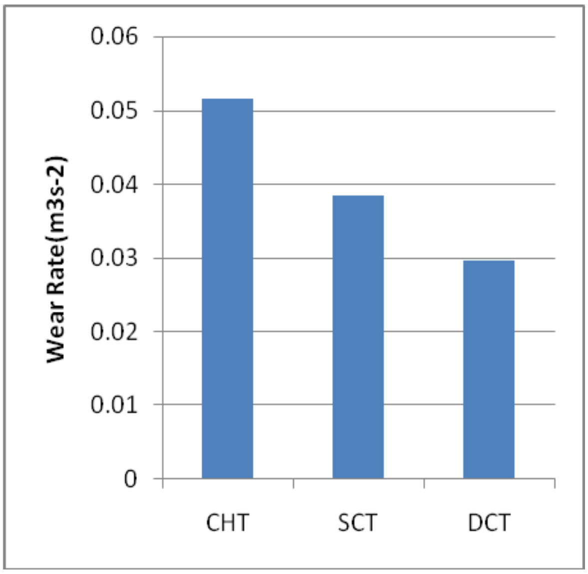

FIG. 5 AVERAGE WEAR RATE V/S TYPE OF TREATMENT (CHT,SCT,DCT)

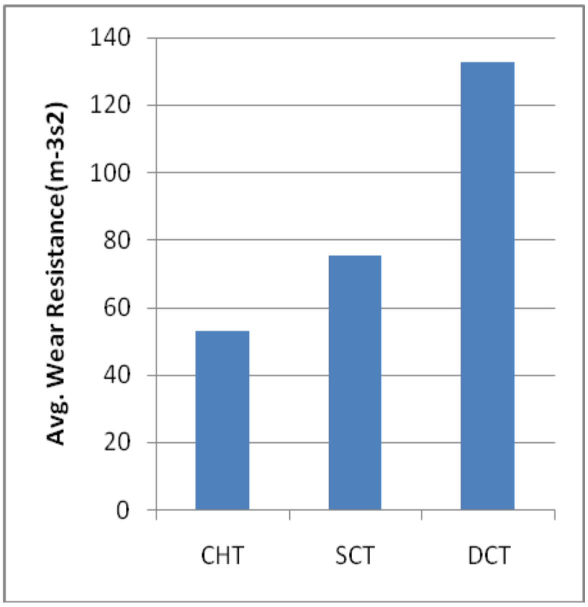

FIG. 6 AVERAGE WEAR RESISTANCERATE V/S TYPE OF TREATMENT (CHT,SCT,DCT)

Conclusions

The hardness of En 45 spring steel increases by 5.6% after the material is subjected to cryogenic treatment. Deep cryogenic treatment ensures the possible maximum enhancement in hardness as compared to conventional hardened steel. The primary reason that can be attributed to enhanced hardness of En 45 spring steel is conversion of retained austenite into relatively hard martensite. The application of lower temperatures such as DCT hasled to smaller and more uniform martensite laths in the microstructure, which also contributesto increasing hardness.

Both types of cryogenic treatments (SCT, DCT) substantially decrease the wear rate of En 45 spring steel compared to the conventional heat treatment. However, the improvement in wear rate by deep cryogenic treatment is significantly higher than that achieved by shallow cryogenic treatment. There is significant increase in average wear resistance of deep cryogenic treatment such as 70% over shallow cryogenic treatment and 154% over conventional heat treatment. Supplement of the deep cryogenic treatment to conventional heat treatment process is helpful to obtain better wear properties.

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